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Intelligent Work Process Engineering System

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ABSTRACT

Optimizing performance on work activities and processes requires metrics of performance for management to monitor and analyze in order to support further improvements in efficiency, effectiveness, safety, reliability and cost. Information systems are therefore required to assist management in making timely, informed decisions regarding these work processes and activities. Currently information systems regarding Space Shuttle maintenance and servicing do not exist to make such timely decisions. The work to be presented details a system which incorporates various automated and intelligent processes and analysis tools to capture organize and analyze work process related data, to make the necessary decisions to meet KSC organizational goals. The advantages and disadvantages of design alternatives to the development of such a system will be discussed including technologies, which would need to bedesigned, prototyped and evaluated.

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1. INTRODUCTION

The behavior of an organization is motivated by its goals. The processes, activities and materials required to meet organizational goals, in turn, define organizational behavior. These activities and processes are sometimes referred to as the value chain of an organization. The value chain activities are critical to the successful performance of the organization in meeting their goals and objectives. The goals of the KSC organization are to launch and recover space vehicles in the service of the greater NASA mission. These goals are achieved as a result of the various work processes and activities performed at KSC and other supporting facilities both contractor and government. Consequently, these activities and processes must be performed; safely, reliably, efficiently and effectively while optimizing cost and the predictability of performance of space vehicles. Optimizing performance on these work activities and processes requires metrics of performance for management to monitor and analyze to support further improvements in efficiency, effectiveness, safety, reliability and cost. Being able to monitor and anlyze these metrics will further enhance KSC operations in the service of their mission. Information systems are therefore required to assist management in making timely, informed decisions regarding these work processes and activities. Currently information systems regarding Space Shuttle maintenance and servicing do not exist to make such timely decisions regarding the specific activities, which must be performed to ensure the safety, reliability, efficiency and predictability of Shuttle processing.

As a case in point, a report identifying Root Cause for Space Shuttle Operations and Infrastructure Costs, was recently developed by McCleskey [1]. His analysis found that ~ 25% of Direct Work costs were categorized as Unplanned Troubleshooting and Repair activities and another ~ 24% of Direct Work costs were associated with Vehicle Servicing. However the specific activities making up these servicing and repair tasks could not be readily identified. The magnitude of these unplanned activities relative to the totality of direct labor, reflects uncertainties and risks in the design of the vehicle. This indirectly impacts the cost for Operations Support, Logistics, Sustaining Engineering, Safety Reliability and Quality Assurance, and Flight Certification, all of which are hidden costs. These hidden costs most importantly make up the greatest percentage of recurring operational expenditures.

If data were captured and organized relative to the tasks making up work instructions, one could conduct a deeper analysis of unplanned as well as planned vehicle processing activities. Management could address work process changes and design changes to reduce costs and risk in the future while improving upon the efficiencies of processing the Shuttle. Start-stop time data associated with tasks related to differing Operational Functions and Design Disciplines could be captured and analyzed to pinpoint specific problems. These problems could then be targeted for improvement in process and or design. This data could also be used to develop models of future design alternatives to make predictions concerning budgetary requirements and the reliability of

designs.

2.0 BACKGROUND KNOWLEDGE: MANAGEMENT INFORMATION REQUIREMENTS AND TOOLS

Management is decision-making and problem solving. In order for management to make informed decisions about the performance of activities regarding the safety, efficiency, reliability and costs of operations, data must be gathered and translated into information regarding these dependent measures. Numerous methods and technologies (i.e. tools) have been developed for industry to conduct the needed analyses for management to make decisions regarding these measures. One of the classical techniques employed is that of the control chart. There are numerous forms of the control chart [2]. In the abstract, however, the control chart is a data mining tool which plots a measure of performance as a function of time. The chart is segmented into three boundaries called the centerline which represents the mean value of the measure of interest, the upper control limit and the lower control limit. The upper and lower control limits typically represent values which represent some number of standard deviation units above and below the mean value represented by the centerline. As the measure of performance is plotted over time one can see how this measure is varying.

Of specific interest, however, is when the measure starts moving toward either the upper or lower boundary. This means that the process is out of control. A visual inspection of the chart will show a slope deviating from a straight horizontal line moving toward one of these boundaries. One can glance at the chart and judge how quickly the process being measured will go out of control by looking at the magnitude of this slope. Figure 1.0 shows a control chart and a trend developing, which would indicate that the process is going out of control. Exceeding one of these boundaries indicates that there is a failure in the process or in the material being measured. This kind of information can be used to prevent or alert operators to the potential failure of a system. Armed with such information management can then make decisions regarding system operability and can trigger an analysis of the causes for the system going out of control. Hopefully, this will preclude any future problems in the operation of the system.

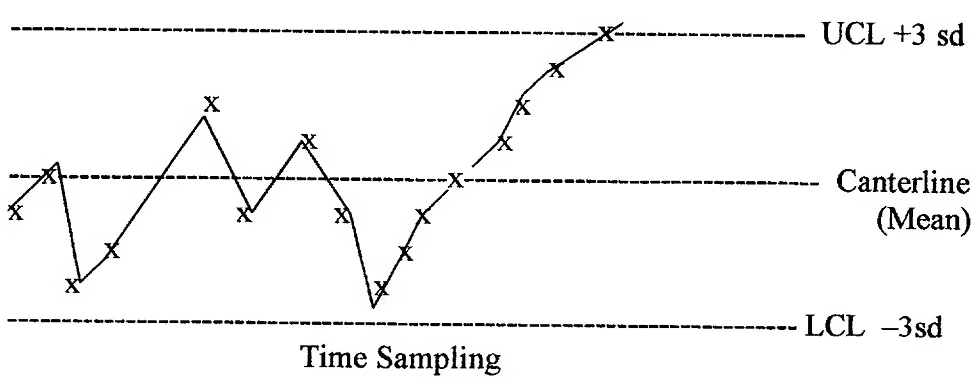

Figure 1.0 Generic depiction of a process control chart showing a trend which is exceeding the

upper control limit of + 3 standard deviations (sd) above the mean.

This type of data analysis can be employed to plot and track the variation of an activity about its expected value in terms of time to complete that activity or to track the performance of a component or system about some expected value indicative of its health. Moreover costs to perform specific activities can be plotted to determine if expected costs are on track, below expectations or exceeding expectations. Other statistical regression analysis techniques can equally well be applied to the types of dependent measures reflective of safety, reliability, efficiency and cost. These techniques can be used to make predictions regarding the time to failure of a component or the time to complete a process given historical data from past records [3]. Madigan and Ridgeway [4] have also described Bayesian analysis techniques for making such predictions and for modeling processes for which prior probability distributions on work metrics are available.

Another type of analysis typically performed by management especially when monitoring organizational performance is that of root cause analysis or drill down. Root cause analysis is a technique for identifying the source or the cause of a specific problem identified. In management information system terms, root cause analysis is performed by drilling down into the various layers of information recorded regarding specific activities of the organization to identify the source of a problem. This is typically a lower level of analysis than that conducted employing control charts of a specific process or system performance. Whereas control charts can indicate that a process or system is about to go out of control, indicating that a special cause for the loss of control is apparent, control charts and trend analyses do not specifically identify the cause or source of the problem. Identifying the source or cause of the problem requires further in depth analysis of the process or system. However with well specified data, recorded at some basic unit of analysis, management can perform root cause analyses on organizational activities employing a drill down capability.

As an example given the analysis performed by McCleskey regarding the apportionment of dollars to direct labor, he found that ~ 50% of the direct labor costs were associated with unplanned activities. However, these unplanned activities could not readily be identified. Consequently, management has still not identified the source or deeper cause for such costs. In essence such costs still remain unaccounted for. However, if data could be captured at a basic, fundamental unit of analysis for work processes, one could identify precisely what tasks are responsible for this large portion of direct labor costs. For example, if data regarding the tasks of a work instruction along with the context with in which the task is performed were captured, such deeper level analyses and ultimate identification of the source of such costs could be specified. Data related to the technical staffing requirements to perform such tasks, the historical safety record on task related work, the time to complete a task, the materials required for the completion of the task, the ground service equipment required for the task, any associated quality assurance support, hazard and safety considerations, as well as, environmental facility requirements and associated costs could be captured and stored in a data warehouse. Armed with this store of data relative to this basic unit of analysis, the task unit and its context, management could readily perform root cause analyses to answer any questions regarding potential deviations

from expected operations along with safety and health concerns.

A third class of management tools, which has recently received broad attention and application in industry is that of simulation and modeling of industrial and organizational processes [5]. These modeling tools allow managers to create chains of input-output processes which reflect the underlying activities of the organization. The inputs to the processes and the processes themselves are the independent variables, which can be manipulated by management. The outputs are the effects of the work processes or the transformations imposed upon the inputs. That is, the results of work performed on the inputs. These outputs are typically referred to as the dependent variables and can be measured to reflect the performance of the processes imposed upon the inputs. What is unique about such tools is that management can experiment with different organizations of tasks within a process, can modify specific processes by introducing new technologies or can change the values of input parameters and receive information regarding the likely impact of such changes upon the performance of the organization. Such tools can also demonstrate where the bottlenecks to organizational performance occur and allow for a deeper analysis of the underlying cause and effect relationships inherent in any model of the organization, process or system. Such simulation and modeling tools have effectively been used to make predictions regarding performance. As a relevant case in point, all of the space missions executed by NASA in one form or another were the products of simulation and modeling tools. The Department of Defense has also directed all services that any future defense program procurements will require that competing contractors supply simulations and models of the operation of the engineering systems to be designed and developed along with models of life cycle development processes for the procured system.

Given the basic unit of analysis, the task and its context, along with the associated data which could be captured for the data warehouse, models can be developed and executed to make numerous predictions. For example alternative sequences of tasks can be modeled to determine if any improvement in efficiency and or schedule can be achieved. Information regarding materials required for the conduct of tasks, the location of task performance, the labor and support required and the schedule of tasks can be used to make predictions which can effect the supply chain of operations at KSC. Such process simulations can supply management with an experimentation platform from which to evaluate improvements which may be associated with proposed changes to operations to foster continuous process improvement.

2.1 Data Requirements for Management Decision-Making To Meet Organizational Goals

In order for management to make decisions based upon the categories of analyses discussed above a basic unit of analysis had to be decided upon which could then be subjected to the various analysis methods and tools. That unit of analysis was determined to be the task level or step level unit embodied in a work instruction. This was found to be the lowest unit of analysis about which various data elements could be recorded during the execution of a work instruction. This unit of analysis was associated with the various data relevant to making the kinds of decisions required on the part of management in order to meet organizational goals. Additionally, a scheme for organizing the needed data was developed such that various analyses

could be carried out relevant to processing the Shuttle orbiter.

The results of the investigation of data required is presented in Figures 2.0-6.0. The investigation of data requirements found that most if not all data required for the conduct of these various categories of analysis could be found in the Operational and Maintenance Instructions (OMI) and their associated runs as well as in the Problem Reporting and Corrective Action (PRACA) data base. The data required was then placed into a structure characterizing this basic unit of analysis, the work step or task, along with its context. That is, this structure defines the work step and the context in which the step is performed. This structure or instance regarding the basic unit of analysis could then be used to organize the data and yield the needed information for the conduct of various analyses for management decision-making. The analysis yielded the following data structure.

1.OMI ID#
2.Step Name
3.Requirement Addressed
4.Operational Function
5.Design Discipline Required
6.Materials Required Yes/No
7.Special Consideration Yes/No
8.Quality Assurance Requirement Yes/No
9.Environmental Requirement Yes/No
10.Safety Requirement Yes/No

11.Accident Report
12.Deviation to Work Instruction
13.P/FRACA
14.Initial Problem Report
15.Materials Costs
16.Skill Codes
17.Start Time
18.Stop Time
19.Date Performed
20.Location Of Work Performed

The first ten rows represented in this data structure are used to classify an instance or the basic unit of analysis. They define the context in which the work is performed and identify the basic unit as belonging to an Operational and Maintenance Instruction (OMI) ID number, row 1.. Within the OMI the basic unit is also given a Step Name, row 2., describing what task must be performed. The remaining rows, 3-10, of this block characterize the work step to be performed as a set of attributes which can take on a finite set of values either Yes/No or some set of nominal values as in Operational Function and Design Discipline Required. These attributes and their values were designed in a manner consistent with the way in which management analysts

typically organize their thinking regarding a work step instruction. This classification scheme was developed as a result of interviews with individual stakeholders who would be the potential end users of this kind of management information.

Rows 11-20 consist of data which is gathered as a result of the actual execution of the work step. This is the data that will be used to perform the various types of analyses discussed for management decision-making. Figures 2.0-4.0 present data flow diagrams specifying how the various data elements within the data structure will be used in the various types of analyses discussed. Additionally, Figure 5.0 indicates how this data may also be used to feedback information regarding Lessons Learned, modifications to Training Requirements and Work Requirements.

2.2 Current Status of Data Generation and Collection Relative to Shuttle Work Processes

Currently, work instructions and their associated data are recorded manually on hard copy paper sheets detailing the work to be performed. This information is then scanned into a document store. No further processing into an electronic format is generated relative to this information. Problem reports on the other hand are first collected on hard copy forms and then transformed into and electronic data base which can be readily accessed for analysis. As a result of this current state, the collection, gathering and organization of the required data to conduct the analyses for management decision-making in large part is none existent. Needed analyses and information organization would have to be conducted with considerable human interaction. A major constraint then is the absence of an electronic format in which the needed data can be captured, organized and analyzed. Therefore although the data exists for such analyses to be conducted it is currently in an inert form. Any analyses to be performed for management decision making is conducted with considerable time and effort on the part of the analyst.

3. Proposed Alternative to the Current System

As an alternative to the current lack of information systems to support management decision-making regarding work processes and work process engineering, a paperless work processing system is proposed. Such a system would include a work authoring tool, electronic work control and instruction execution capability, a data warehouse which can filter needed information and automatically organize this information for analysis purposes, process analysis tools for analyzing work results and a feedback loop to incorporate changes that could help reduce cost and improve on work efficiency, scheduling, safety and resource allocation This system could model work processes to make predictions regarding; the costs and schedules associated with alternative vehicle design configurations, the reliability and safety of a work processes, time to execute a work process, utility of a work process, cost of implementing a work process in material, support and labor. In short such a system would allow the various categories of analysis to be conducted for management decision-making.

The benefits of such a systems would allow management to: monitor and set control limits for work related measurements, identify uncertainties in work processes as targets for continuous process improvement, identify excessive costs related to work processes, identify root causes for operational costs and hazards, predict actual time and costs for processing orbiter and for estimating operational budgets, provide needed information for analysis of design inefficiencies, provide feedback for developing and updating work requirements, training requirements, lessons learned, and safety in the performance of work and the integrity of the orbiter.

3.1 Description of Proposed Work Process Engineering System

3.1.1 Work Instruction Authoring

The alternative system proposed to meet the needs of management is graphically depicted in Figure 6.0. This system design presupposes that the current process for recording and storing data relative to work processes, lends the data inaccessible by way of standard electronic processes. Consequently this alternative would begin processing work instructions with the aid of an intelligent work instruction authoring system. This system would place all work instruction information into an electronic format capable of being stored in accordance with the data structure outlined above. Work instructions and their component steps would be uniquely authored or retrieved in whole from existing data sources which store the components of the work instructions. The work instructions could also be subjected to modification if needed by the user. New work instructions could also be developed and designed in accordance with accepted human factors principles by accessing a task analysis system. The task analysis system would guide the user through a task analysis process and then access other tools to assess the human factors issues, which must be addressed in the design of the work instruction. Upon completion of a work instruction all of the information regarding the attributes of the work unit would have been provided for sorting in the Work Unit Warehouse.

Issues which must be addressed regarding the authoring of work instructions would include but not be limited to: the human interface, the structure of the interview process to elicit information from the user, the format and media to be employed relative to differing types of information to be communicated to personnel performing the work process, the human engineering principles which must be accessed and implemented employing the human factors tool kit, the differing types of intelligent search routines required to gather stored information when needed to facilitate the construction of an OMI and other intelligent systems required to store work instructions and their component steps in a data warehouse which is self-organizing and adaptive.

3.1.2 Electronic Work Instruction Distribution

The output from the authoring system would be transmitted electronically to personnel responsible for scheduling the execution of the work process and to a data base of work instructions. The instruction could alternatively be transmitted to an intelligent work scheduling system which could automatically schedule the work activities, the supply of needed materials,

ground service equipment, environmental facilities where the work would be performed, the necessary technical crew and support personnel. The information upon which such decisions could be made would be contained in the first block of attributes describing the task step and context for the work unit as well as from data contained in the data warehouse.

The needed personnel, facilities, material requirements and schedule for the work unit along with the work instructions, could then be received via wireless transmission by the appropriate personnel by way of a personal digital assistant (PDA). Personnel could then enter the raw data relative to performance on the task during task execution employing this PDA. Data recorded would consist of that specified in the second block of fields in the data structure designed. Information regarding problem reports could also be entered by this system such that it could be transmitted, received and stored in the existing PRACA data base electronically. Consequently upon completion of the work instruction, the information needed to categorize a work unit or work step and the data associated with the performance of the work step would be available for storage, organization and retrieval in the Work Unit Warehouse of information.

3.1.3 Work Unit Warehouse

The Work Unit Warehouse would provide managers with the needed store of information and data required to conduct the various analyses for management decision-making. The warehouse would consist of an interface for users to create their own organizations of data and information if desired, as well as, machine learning algorithms which would automatically cluster information contained in the basic work unit data structure specified or some other unit of analysis specified by a user. That is, a user could construct their own database organized differently than that specified by the data structure defined. This of course is contingent upon the fact that the information and data is contained in the work instruction database or other databases, which could be accessed by the warehouse routines.

In order to develop such a warehouse an appropriate machine learning algorithm must be provided to automatically retrieve, sort and classify information relative to the basic unit of work, to be subjected to various analyses. One potential algorithm is CLASSIT developed by Fisher [6]. CLASSIT is an incremental concept formation algorithm, which takes instances made up of a set of attributes and their associated values and automatically finds the best clustering or organization of these instances. For the case at hand, CLASSIT would sort and organize work unit information based upon the attributes and their associated values as specified in the basic unit of analysis defined. The categories, which evolve after processing numerous instances, would represent classes of information, which are inherent in the instances fed to the algorithm. What is unique about CLASSIT is that the conceptual clusters that are formed correlate extremely well with those categories, which would have been developed by humans given the same instances. Given this current design each instance, which is fed to CLASSIT would also be associated with a record which identifies all of the data recorded as a result of the execution of a work unit. So for example, if one wanted to determine how many PRACA reports were filled out relative to a specific Design Discipline, one could query CLASSIT and retrieve all of the problem reports associated with that Design Discipline. Any questions regarding the

attributes of a work unit or the data associated across work units could be retrieved with this system. All of the analyses specified for management to make their decisions regarding the goals of the organization could be conducted given the data stored in this warehouse and the organization of the data provided by the algorithm. The advantage is that no predefined structure for the database of information in the warehouse is required. This provides the needed flexibility for organizing information in various ways, to meet managers information needs. Information could essentially be sorted and organized based upon any combination of attributes and data stored as defined by the basic unit of analysis.

The features of CLASSIT, which are of importance for organizing information, are presented in the following. CLASSIT differs from other algorithms in that it can not only organize information automatically, but it can modify its organization based upon new instances to be sorted. That is, it is self-organizing. CLASSIT operates in an unsupervised fashion. It does not require any feedback as to the goodness of fit of the categories it forms, unlike many other algorithms, which do require some form of external feedback. Due to the incremental nature of this classification algorithm initial instances may bias the clustering of new or future instances to be processed. However, CLASSIT continuously evaluates a current organization of information such that it can form new classes, merge existing classes and split existing classes to improve upon its ability to discriminate between instances, which do or do not belong together. This is accomplished by way of a category utility measure. The expression for **category utility** is based upon conditional probabilities and is expressed as follows:

Eq [1]

$$\frac{\sum_{k=1}^{K} P(C_k) \sum_i \sum_j P(A_i = V_{ij} \mid C_k)^2 - \sum_i \sum_j P(A_i = V_{ij})^2}{K}$$

If new attributes are to be added to an instance or deleted from an instance, CLASSIT has the capability to modify an existing organization to form a new organization of the information based upon the addition or deletion of attributes and their associated values. CLASSIT is also one of the only algorithms, which was designed to simulate human performance on classification tasks. The resultant classifications therefore would be most compatible with human organizational processing of the information. This algorithm can handle missing data and missing attribute values since it is stochastic in nature. It can accommodate nominal as well as quantitative values.

CLASSIT forms categories of instances in a hierarchical fashion with the most general classes of information toward the top of the hierarchy and the more specialized categories toward the bottom of the hierarchy. Each specific instance would be stored as a singleton class under its parent category. An instance may also belong to more than one different category at any given level of organization if the instance cannot be clearly discriminated. This is called clumping and has also been observed in human information processing.

The category utility function of equation [1] is used to classify a new instance into an existing class, to create a new class (i.e. a singleton) to combine two classes into a single class (i.e. merging) or to divide a class into several classes (i.e. splitting). When a new instance is to be sorted it is first placed in the root node. At this node as in all other nodes, the system computes the probability of an instance occurring at that node. This probability yields the $P\,(C_k)$ value, which represents the probability that an instance would belong to any given node, which has been created. CLASSIT also computes a conditional probability for each attribute and its associated value. This is represented as

$$\sum_i \sum_j P\,(A_i = V_{ij} \mid C_k)^2 \ .$$

This is the sum of the probabilities of the attributes having specific values given that they belong to a specific class. It is referred to as the predictability of attribute values belonging to a given class. If an instance and its associated attribute values match the probabilities associated with attribute values of an existing class then there is a high probability of that instance belongs to that class.

However this conditional probability should be adjusted by the probability of the attribute and its value occurring independent of any specific class. This is called predictiveness and is represented as

$$\sum_i \sum_j P\,(A_i = V_{ij})^2.$$

That is if an attribute and its value has a high probability of occurrence independent of membership to any specific class, then it is not providing much information regarding class membership since it is highly likely to occur independent of class membership. The number of classes, which the category utility function is evaluating is represented as **K.**

Once an instance is placed in the root node it is then passed to each child of that root node and the measure of category utility is applied to each child to determine to which node the new instance most likely belongs. If there is a match to any of these children which ever has the highest score will retain the new instance. If none of the children match closely, then CLASSIT will consider forming a new singleton class based upon the category utility measure. If two or more of the children match the instance closely, then CLASSIT will consider merging the instances together into a single class. CLASSIT also considers the inverse operation of splitting

nodes. If CLASSIT decides to classify an instance with an existing category it also considers removing the category and making the instances in that category children of that categories parent. That is the category is removed and the instances, which belong to that category are elevated to become directly linked to that categories parent. In essence they now become candidates for new categories if the category utility function indicates an improved clustering. This entire process is iterated for each node that CLASSIT visits during its attempt to sort a new instance. In this way CLASSIT is continuously modifying its organization based upon the probabilities calculated with the introduction of a new instance into the system.

3.1.4 Search Agents

The Work Unit Warehouse could also contain search agents, which would search the Work Instruction Data Base and retrieve the information required by the basic unit of analysis. This would then create the instances required for sorting by ClASSIT in the Work Unit Warehouse organizing the information for analysis by managers. If the data regarding the basic unit of analysis is captured and stored employing an Intelligent Work Instruction Authoring system and an electronic mode for capturing data relative to the execution of the work instruction, these agents could be easily designed. Since the data regarding a work instruction and its execution is captured in an electronic format with a known structure, simple If-Then rules could be created to retrieve the necessary data for insertion into the slots of the basic unit of analysis. This would require that someone knowledgeable about the structure of the Work Instruction Data Base and the information needed for insertion into the basic unit of analysis, create the simple If-Then rules. Rules could be developed for the retrieval of any element of information in the Work Instruction Data Base. Data elements could then automatically be retrieved and inserted in their appropriate slots in the basic work unit data structure. Again this scheme presupposes that data regarding the basic unit of analysis be captured and recorded electronically and placed into a structured database.

3.1.5 Advantages of Design

The advantages of this design is that the cost to generate work instructions would be reduced due to the facilities provided in the authoring tool which would automatically search and retrieve the needed information for the user. A paperless format would also eliminate the costs for archiving and distributing multiple hardcopies of work instructions to the appropriate recipients for management and execution of the work instructions. The system would also supply the user with the flexibility to organize data and information in accordance with the users conceptualizations, dynamically, in real time.

In the absence of a data warehouse requests for alternative organizations of information would require that information systems personnel specialized in the interfaces of various data bases write routines to gather and organize the data in accordance with a request. This could take days if not weeks to achieve dependent upon the personnel resources available. Moreover, the self-organizing properties of CLASSIT would reduce the costs accrued in developing a model for database storage and retrieval. The traditional approach to database design can be an expensive

process requiring considerable analyses of user needs and information storage and retrieval requirements. Once a structure for a database model is settled upon the structure of the database is fixed. Any modifications would require considerable effort. This would all be eliminated employing CLASSIT.

3.1.6 Disadvantages of Design

The disadvantages of this proposed design would include the cost to develop an intelligent work authoring instruction system, the costs to implement wireless communications, PDA hardware and software, the cost of a data base management system for the Work Instruction Data Base, and the costs to integrate the CLASSIT algorithm and associated agents with the Work Instruction Data Base. A user interface for the Work Unit Warehouse would have to be designed and developed. Interfaces connecting The Work Unit Warehouse with the various analysis packages for management decision-making would need to be developed. Lastly any modifications as to the way in which work is performed relative to the status quo would probably result in change order requests on the part of the contractor associated with increased costs.

3.2 An Alternative Approach

An alternative effort to that proposed in the above would make use of the current system for processing work instruction documents and executing work instructions. This alternative would also use existing document and data stores to capture the needed information required for constructing the basic work unit data structure. The development of the work unit warehouse would consist of the same effort as that described in the above with the exception that research would need to be conducted in the development of semantic search agents to identify and retrieve information regarding the attributes of the data structure and the raw data associated with the execution of the work unit.

3.2.1 Semantic Search Agents

Current search agents employ a simple key word search for information stored in various databases. These key words can form conjunctions of terms as well as disjunctions of terms. They are simple Boolean Logic expressions. The number of terms is also typically constrained to two or three terms making up an expression. The search simply consists of recognizing the words making up the expressions and retrieving information which matches the key word expressions. The underlying meaning of the expression used for the search is not sought. In order to conduct such meaningful searches the technology currently employed is natural language processing (NLP). This technology takes as an input a grammatical sentence, which represents the meaning of the information which is the target of the search. In order to establish the meaning of the expressions, the system must first parse the sentence grammatically and then interpret the meaning of the words making up the sentence to understand the query. Once the target of the query is understood the system can conduct a search and retrieve the desired information. The problem is that the words used in the query must be represented by the system in advance such that an understanding of the expressions can be identified. Considerable knowledge engineering

is required to develop such systems. For general purpose applications such systems are cost prohibitive if they can even be developed to work.

On the other hand a system could be designed which interviews the user and elicits from the user, his/her semantic representation of the target of the search. This approach would not require any form of natural language processing and would place the burden of establishing the meaningful representation of the query upon the user interacting with the system. The challenge then would be to design an interface, which could elicit such meaningful representations from users. If this can be achieved then, general purpose searches can be made of existing data sources to retrieve the needed information. This is necessary since in many cases users searching for information would not know the contents of the many legacy data bases which exist. The user could engineer his/her understanding of the meaning of the information, which is the target of the search, launch an agent with this representation and receive responses which identify sources of data consistent with the users meaningful representation. It would then be up to the user to decide if a particular data store would be of interest. The user could browse through data store retrieved to determine if specific elements of information are located there. If so then the site would be flagged to indicate that the user request is associated with the specific data store and a rule would be coded which points to that site given the representation provided by the user.

This would not require the creation of new data capture technologies and a new data base management system as would be the case with the original proposal. The needed data could be retrieved, encoded and stored to conduct the analyses of concern employing the data warehouse. Such a capability is a compromise between a keyword system and a natural language processing system. Keyword searches are limited in that they consist of simple Boolean expressions and do not have associations to equivalent forms of these expressions. Natural language processing on the other hand, requires considerable engineering of the complete vocabulary of the domain of interest along with complex parsing mechanisms. Such systems are still limited in terms of their ability to resolve ambiguous expressions entered by the user. Consequently, a system, which elicits from a user the representation of the users meaningful representation of a search topic, would limit the necessity for engineering an entire domain vocabulary. Also the need for complex understanding and generation of English sentence expressions as is the case with NLP, would be eliminated. In time various search agents would be developed by differing users within the organization and made available to other users in a library of search agents.

3.2.2 The Representation of Meaning

In order to design such a system however, one must understand the nature of human associative memory, which is the seat of meaningfulness. Since the meaningfulness of something is the product of an individuals stored experiences in memory, in order to understand meaning one must examine the structure of information in human memory. The approach taken herein was first to collect the works of the foremost researchers and theorists with respect to human memory and the representation of meaning, second, to examine their thinking regarding the representation of meaning in memory, third, to find some common ground amongst these theorists and fourth to come up with a set of guidelines or principles which could guide the design of an interface for

eliciting meaning from a user.

The primary sources for theoretical and empirical research were Anderson [7],[8] and [9], Anderson and Bower [10], Quillian [11] and [12] , Kintsch [13] and [14] and Ausubel [15]. These investigators are considered to be the most prominent in the field of human memory. In common to all is their agreement on the obvious fact that memory is associative and therefore meaning is represented by a variety of associations in memory. Therefore to understand meaning one must examine the types of associations, which can be formed in human memory.

Of particular importance in defining how meaning is represented is the classification scheme for meaningful representations espoused by Ausubel [15]. True of all disciplines, either arts, sciences or engineering, in order to understand a subject matter classification comes first. Ausubel [15] has proposed a threefold classification of types of meaning. The first and most basic form of meaning within this classification is that of representational meaning. Representational meaning is defined as words or symbols which represent corresponding objects. This is typically what takes place when one is learning a vocabulary. It involves rote learning, that is the simple assignment of a name to an object. Representational meaning must come first in that the individual must have a name for something that s/he is referring to. Representational meaning involves supplying that name for something. It establishes an equivalence between a verbal symbol and a referent. There may also be different verbal symbols which establish the same equivalence relations. That is different words referring to the same thing. Representational meaning however is not flexible or general in that it has a very specific referent.

The next type of meaning is that of concept meaning. Concept meanings are generic or categorical in nature. They are general and they are flexible. They are ideas, which like representational meaning have verbal symbols, but the symbols have no specific referent. That is, the meaning of the symbols represents an entire class of instances or things, which share some common attributes. These attributes provide distinguishing characteristics, that provide the meaning for the concept. Concept meaning is typically abstracted by experiencing many instances of something and recognizing similar features between these instances. The human information processing system performs this kind of function naturally. For example a child who first experiences a ball object may assign the representational meaning of ball to that specific object. That meaning however only refers to that specific ball and no other types of balls. With further experience, the child sees other round like objects, of differing colors and sizes which can be manipulated in the same way as the first ball experienced and abstracts common criterial features. The word ball no longer represents a specific object called a ball but represents a whole class of specific objects which can be referred to as ball. Given this evolution of experiences, representational meaning come first, followed by the formation of a concept. As we gain more experience with objects most words take on meanings, which are conceptual in nature. That is the names assigned to represent objects or ideas in our experiential base are typically conceptual in nature. As concepts are formed other exceptional features can be taken on to modify our notion of the concept. Hence they are flexible and generalizable. For example a football can take on many of the same characteristics as a ball since it shares similar properties with respect to how it is used and manipulated although its shape is a not round but elliptical.

The elliptical shape is an exception but can easily be taken on to further specify the instances which can be classified as ball.

The third type of meaning employing Ausubel's scheme is called propositional meaning. Propositional meaning expresses a relationship. The relationship is a comment about something. Propositional meaning is formed by a combination of concepts that are combined to each other such that a new idea is formed. This new idea is more than the sum of its component concepts. For example the proposition "semantic network", is made up of two concepts which means something more than the concept "semantic" and "network" on their own. When these concepts are combined they refer to a web of associations between words, that defines the meaning of the words relative to other words in the neighborhood of words to which they are associated. Other examples of propositional meaning may define the relationship between mass and energy or between heat and volume etc. Most English sentential expressions yield prepositional representations in order to establish meaning.

Anderson and Bower [10], Quillian [11] and [12] and Kintsch [13] and [14] all support the notion of the propositional representation and the concept for establishing meaning in memory, although they may use different verbal referents. For example, Quillian [12] refers to "property information" as the basic building block for meaning. This property information is essentially a labeled association or a relation, a proposition. Examples of such property information would consist of; verb phrases, relative clauses, adjectival or adverbial modifiers or any verb and its object. The other fundamental units are referred to as types and tokens, a token being a member of a type. That is types represent classes or concepts and tokens represent characteristics or modifiers of a type. Tokens themselves may serve as types subsuming other tokens, which in turn modify them.

The other theorists reviewed also propose that propositions and concepts can be nested within other concepts or propositions forming a heterarchical network representing all of the potential associations of concepts and relations. All agree on some form of subset-superset structuring of concepts, which forms a hierarchy of meaning typically in a top down fashion moving from general to specific. That is with experience meaning becomes organized moving from high level concepts or propositions to low level instances or instantiations of the concepts or propositions. Quillian additionally proposes that the attributes or tokens of a type can take on different weights which indicate how indicative that attribute is of identifying membership to a type. Highly weighted tokens are more predictive of a type's membership than low weighted tokens. This allows for considerable flexibility in making predictions regarding membership to a class or type. Anderson [7] and Kintsch [13] also support this notion of strength of association or activation between attributes and their respective associations.

With respect to differing types of meaningful representations, then all of the theorists are in agreement as to prepositional and conceptual classes of meaning although they have not explicitly identified them as classes as has Ausubel. Most, if not all, agree that the most prevalent forms of memory for meaning consist of concepts and propositions idealized as a network of associations made up of concepts and the myriad of relationships they can form

dependent upon the context in which they are used. The context of textual information therefore is also an important component in establishing the meaning of a target of search. This context forms the neighborhood of words, which provide meaning for the target under search and would govern what gets visited.

3.2.3 Contextual Relations

These propositional relations and subset-superset hierarchies forming concepts defines what is referred to as the context of relations or associations between the words. It is this context of relations and associations, which forms the meaning of an expression. The search for information consistent with a users understanding of the meaning of the target must then incorporate those word units and their associations making up this context of relations. All of the theorists reviewed agree that such associations are what provides for meaning in human memory. Therefore, the context of relations or associations must be defined by a user to represent the users meaning for the target of search. Identifying the kinds of associations and relations would then define this context and represent the meaning of the information targeted for search by the user.

First of all as indicated by these theorists the meanings of concepts are represented as a hierarchy of associations between the concept name and the attributes which define the meaning of the concept. In turn the names of attributes and the name of the concept may have representational equivalents. That is they may be known by different names. The structure for representing a concept would then look like a tree. The concept name would be the top level node of the tree and the attribute names would serve as the first layer of nodes linked by downstream arches from the concept name node as in Figure 7.0

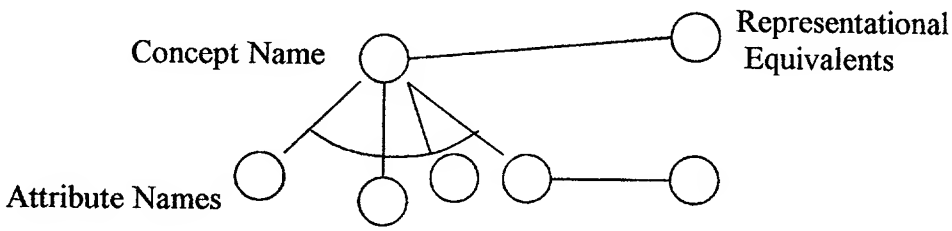

Figure 7.0 Nodes and links representing a concept and its defining attributes along with representational equivalents.

The nodes of Figure 7.0 would represent word units which represent the verbal names assigned as the concept name, the names of attributes and the representational equivalents to the concept name and attribute names. The attributes are ANDed together representing a conjunction of terms which are the defining characteristics of the concept. A concept name and or the names of its defining attributes may also have equivalent representations. These would be different words that could be used to define the same characteristics or the same concept name. They would be

represented as a disjunction of terms or they would be ORed. These names for the concept and the names for the attributes would be elicited from the user along with any of their representational equivalents. If the user can not recall representational equivalents then the system can make use of Word Net. Word Net is an ontology of English words which provides alternative representations for English language terms and currently consists of over 100,000 words and growing. It can be downloaded free from the DARPA web site or from Princeton University. Equivalent terms for the names provided by the user can be retrieved and examined by the user for their appropriateness as representational equivalents. It may be that the concept name and its equivalents along with the attributes of that concept and their equivalents can be automatically retrieved and inserted from Word Net into the users representation of the meaning of the target. The user could then inspect this representation and edit it if desired.

During the process of building this concept tree, the attributes may also represent concepts, which in turn must be decomposed into their associated attributes. The process would be continued until the user makes a judgment that no further decomposition is required. In addition to specifying the concept names and attribute names the user would also be required to indicate the strength of the relation between the attributes and their associated concept. This feature is borrowed from the concepts of associative strength or activation from Anderson [8] and [9] from Kintsch [13] and [14] and from Quillian [11] and [12]. In many cases a search which is being conducted comes across documentation which does not explicitly mention the concept name or its equivalents but does mention some number or all of the attributes. This would imply that the document is associated with the concept dependent upon the amount of evidence found related to the attributes mentioned. The weights or strength of association between the attributes and the concept name could then be used to determine if the document is truly concerned with the concept in question. If attributes with high valued weights relative to their association with the concept are found then the evidence is in favor of recognition of the concept. If not then the concepts relation to the document would be questionable. The amount of evidence in favor of a concept would be specified by the user.

If the subject of a users search is a propositional expression or a combination of concepts, then the user would be requested to enter the expression into the system which best represents the users understanding of the target for search. This would more than likely not consist of more then three or four words, which is the limitation of most phrases. Any articles or prepositions would be ignored by the system and the concepts making up the expression would become the topic for decomposition. Again the user would be requested to supply alternative expression equivalent to that originally specified. For example, one may want to conduct a search for the proposition "semantic representation". This could equivalently be expressed as the "structure of declarative memory", or the "representation of meaning in memory", or "cognitive models of meaning", etc. Each of these propositions equally (in my mind anyway) represent the meaning of what I am searching for. These propositions are made up of a combination of concepts each of which independently does not refer to the target of the search. However their conjunction would more then likely get me to the specific information I am looking for. However, the combination of words used in different documents may not be the same as any one combination or expression listed. Therefore one would need to decompose each concept in each proposition

in a similar fashion as that described for a single concept term. If any conjunction of terms representing the various representational equivalents of the concepts making up these equivalent expressions is found then this would indicate that the meaning of what I am looking for is contained in the document or database.

Again the process for representing the meaning of a proposition could be aided by retrieval of individual concepts and attribute names from Word Net. If this is the case then the task becomes less difficult for the user. However in many technical domains the terms used would probably not be represented in Word Net and the user would have to be guided through a process of defining referential equivalents to their expressions and to decomposing each into their component parts. The component parts must then further be decomposed as singular concepts and weights would be applied to their links as before. The search process then amounts to a search for evidence in support of a specific meaning. The meaning is inferred from this evidence regarding the conjunction of disjunctive terms. That is several trees would be constructed to represent each concept and its associated disjunctive equivalents. If any of the attribute names or their equivalent representations are true then the attribute is true. Likewise if any of the concept terms or their equivalent representations are true then the concept term is true. If the concept terms are all true then the proposition is true. The conjunction of these concepts would represent the prepositional relationship of choice. Partial truth may also be represented by propagating forward the weights assigned to any attributes strength of association with any given concept. The user can set the degree of truth which is acceptable during a search for meaning. Thus even partial truth in satisfying the meaningfulness of a target can be retrieved and examined by the user. Any documents which are found as a result of conducting these multiple searches on the conjoint terms and their representational equivalents, could then be compared for their intersection. These would most likely be the documents which would most closely match the meaning of the target of interest.

This type of search bears similarity to the use of Bayesian equations to classify text documents. The equations are made up of expressions representing the probability of a specific class of document being found in general and the cross product of the probabilities of some number of words being conjointly found within a given document. This type of algorithm has been found to be capable of reading documents on news group pages and correctly classifying them into one of twenty different categories of news Mitchell (1999). The Bayesian equation for classifying such documents is as follows:

$$\text{Eq. [2]} \quad P\,(D_i \mid A_i = V_{ij}, \ldots\ldots\ldots, A_n = V_{nj}\,) = \underset{i}{P}(D_i)\ \Pi\, P\,(A_i = V_{ij}\,)$$

This simply states that the probability of a document belonging to a specific class given that specific words are evidenced is equal to, the probability that the class of document would occur in your experience, in general, times the cross product of the probability of the words occurring. This assumes that words can occur independent of the occurrence of other words in a document.

Although this is obviously false it works very well. It is referred to as a Naïve Bayes Assumption.

Consequently, meaningful search is likened to classifying documents, which belong to certain categories of information, very much like the type of meaningful search, which is being proposed herein. Consequently there is conceptual evidence due to the similarity to the Bayesian classification scheme that such a process would work to successfully retrieve meaningful information.

4. CONCLUSIONS/FUTURE RESEARCH

Future research can focus upon the first alternative specified as defined in the scheme presented in Figure 2.0. Another alternative is to develop the semantic search capability, evaluating it empirically with users to determine agreement between the searched for target and the users confirmation or disconfirmation of information retrieved. If the empirical evidence supports the validity of the semantic search capability then it would be developed and integrated with the Work Unit Warehouse and its classification algorithm. A third option would be to develop the first alternative and also conduct research to develop the semantic search capability. The semantic search capability would have widespread use across the various divisions of NASA as well as having considerable commercialization potential.

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